Supporting Information for:

Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness

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The number of tables: 20

1. Model Year Difference between Diesel and Electric Trucks in Consideration

Despite the similarities between the diesel and electric trucks in Table 1, the model year of the diesel truck (2006) is older than its electric truck counterpart (2011). Considering medium duty diesel engine and vehicle technology developments since 2006 (*1*), there may have been at most a 12% improvement in the fuel economy of gross vehicle weight (GVW) class 5 trucks. We include the possible fuel economy improvement between 2006 and 2011 as one of uncertainty factors in the total cost of ownership (TCO) and life-cycle energy use and greenhouse gas (GHG) emissions model.

2. Drive Cycles and Fuel Economy Variations

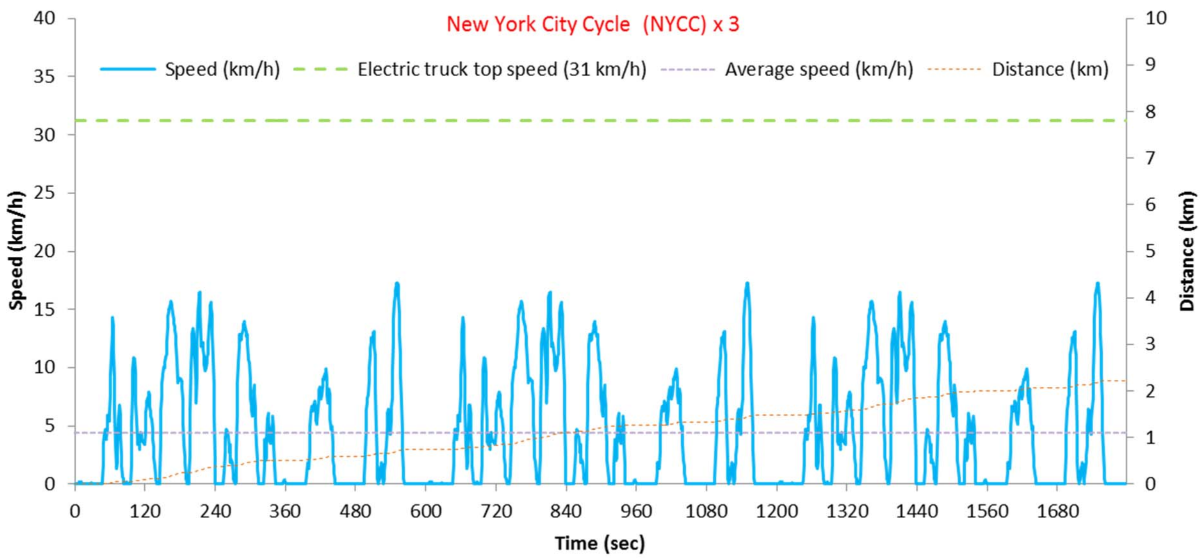
Drive cycle[1] (speed vs. time schedule) affects vehicle energy consumption. Based on the dynamometer test result of the GVW class 5 FedEx diesel delivery truck in Table 1 (*2*), we consider fuel economy variations according to three different drive cycles: the New York City Cycle (NYCC), the Orange County Transit Authority Bus Cycle (OCTA), and the City-Suburban Heavy Vehicle Cycle (CSHVC) (*2*). These three drive cycles are shown in Figure 1S. Originally, the dynamometer test was conducted on the NYCC, OCTA, and HTUF Class 4 PDDS (Hybrid Truck Users Forum Class 4 Parcel Delivery Driving Schedule). However, since the HTUF Class 4 PDDS was customized/modified for the dynamometer test and the original drive schedule is not available, we chose the CSHVC as an alternative. The drive cycle is often characterized by kinetic intensity (*3*), which can be interpreted as below:

$$\frac{acceleration\ associated\ with\ vehicle\ inertia\ and\ road\ grade}{\left(\frac{average\ cubic\ speed\ associated\ with\ aerodynamic\ drag}{average\ speed}\right)}$$

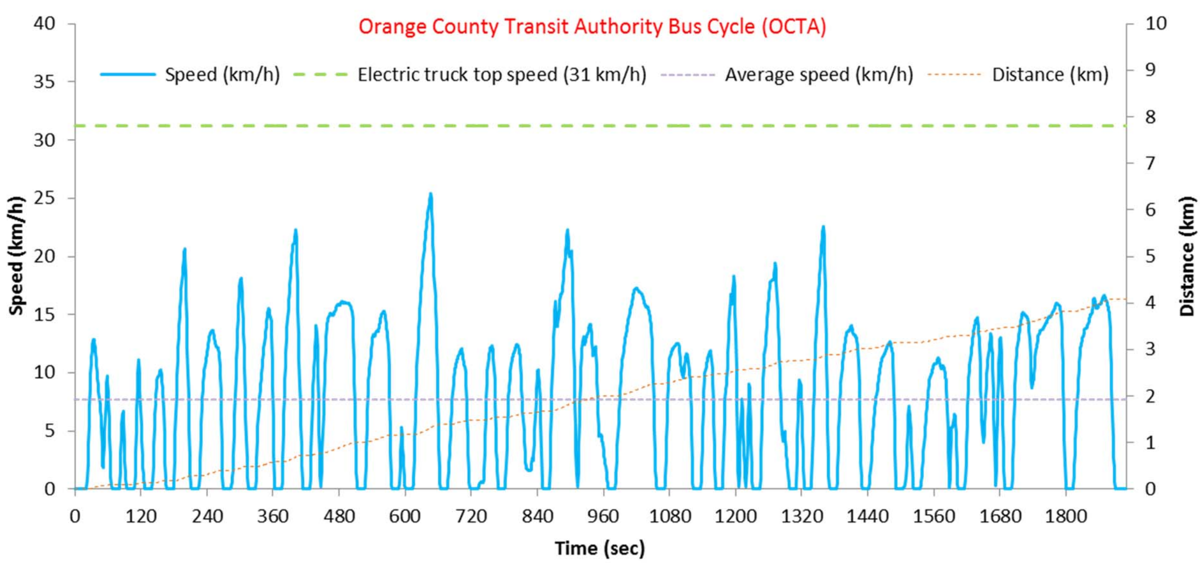
Based on the kinetic intensity range, we believe that the NYCC, OCTA, and CSHVC well cover and represent the reported FedEx diesel delivery truck operations (*2*), also complying with the electric truck capability (e.g., top speed constraint of 50 miles or 31 km per hour).

The dynamometer test was carried out with a payload of 450 kg, but we assume full-load (2,835 kg for diesel truck) operation. Using a vehicle dynamic simulator – Future Automotive Systems Technology Simulator (FASTSim) (*4*), we adjust the dynamometer test result for the payload difference (2,385 kg), as shown in Table 1S. We use a diesel-powered Sports Utility Vehicle platform to find a relationship between payload and fuel economy. Simulation parameters are listed in Table 1S. We estimate base CSHVC fuel economy, based on kinetic intensity and dynamometer test data for OCTA and modified HTUF Class 4 PDDS. Considering vehicle dynamics, we assume a linear effect of kinetic intensity and payload on fuel economy. In addition to fuel economy variations for the three drive cycles, we also consider the possible fuel economy improvement over time discussed in the previous section.

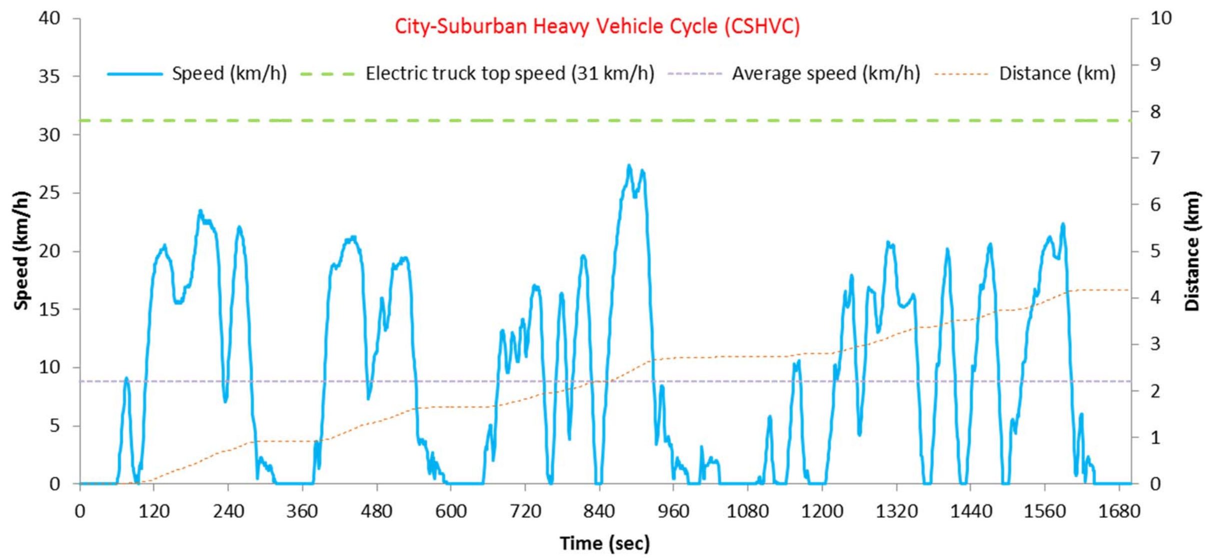
[1] Drive cycle is distinguished from duty cycle which is more associated with vehicle load (e.g., payload and grade), operation range and distance, etc.


New York City Cycle (NYCC) x 3
Speed (km/h)
Electric truck top speed (31 km/h)
Average speed (km/h)
Distance (km)
Speed (km/h)
Distance (km)
Time (sec)
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680

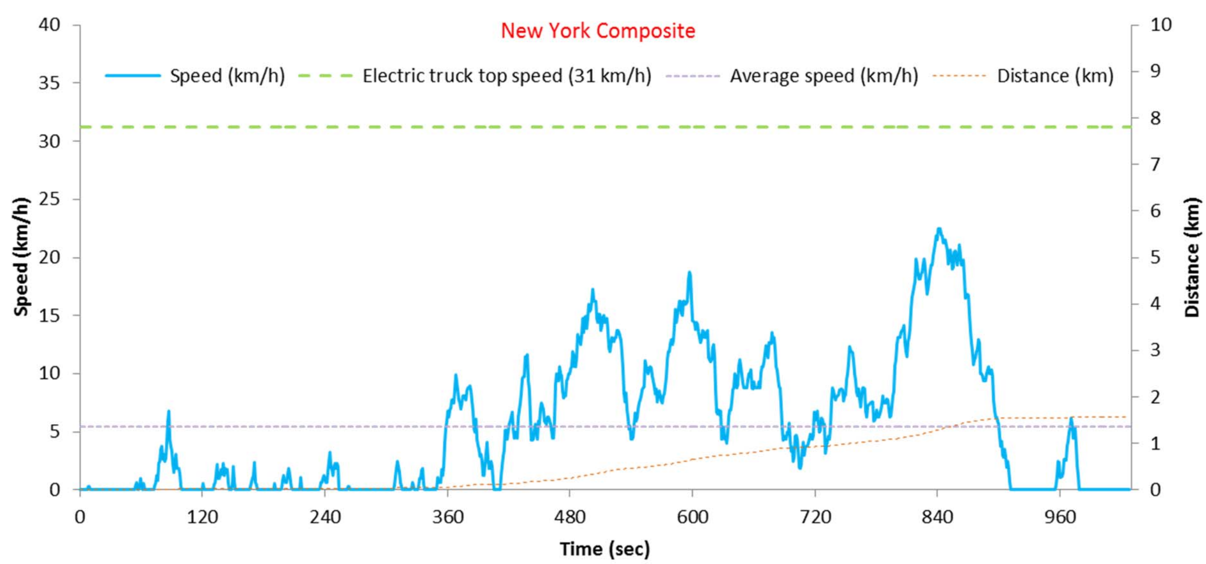
(a) NYCC


Orange County Transit Authority Bus Cycle (OCTA)
Speed (km/h)
Electric truck top speed (31 km/h)
Average speed (km/h)
Distance (km)
Speed (km/h)
Distance (km)
Time (sec)
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800

(b) OCTA



(c) CSHVC



(d) New York Composite

Figure 1S. Drive Cycles – NYCC, OCTA, CSHVC, and New York Composite.

TABLE 1S. Drive Cycles and Fuel Economy at Full Load

Parameters for diesel-powered vehicle simulation to evaluate payload effect on fuel economy			
Drag coefficient	0.5	Cargo mass (kg)	500 – 2,500
Frontal area (m^2)	4.63	Engine power (kW)	150
Glider mass (kg)	4,365	Tire radius (m)	0.4
Wheel base (m)	3.9	Rolling resistance coefficient	0.01
2012 Volkswagen Touareg TDI was used as a base platform with the parameters above adjusted to reflect the difference between SUV and medium-duty truck, based on vehicle test/activity data (*2*, *5*).			

Payload effect on fuel economy (simulation result)			
Payload (kg)	Drive cycles and mpgge (mile per gasoline gallon equivalent)		
	NYCC	OCTA	CSHVC
500	8.3	10.9	12.8
2,500	6.5	8.7	10.2
Δ Payload (kg)	2,000		
Δ mpgge	1.8	2.2	2.6
% Δ mpgge reduction per kg	0.0108	0.0101	0.0102
	0.0104 (average)		

Dynamometer and field test fuel economy result (*2*)				
Payload (kg)	Drive cycles and fuel economy (mpg)			
	NYCC	OCTA	Modified HTUF4	CSHVC
450	6.08	9.52	11.66	11.37 (estimated based on KI)
Kinetic Intensity (KI) (1/km)	5.2	2.2	0.8	1.1
Full payload (kg)	2,835			
Δ Payload (kg)	2,385			

Estimate of fuel economy at full load (mpg), based on dynamometer data and payload effect above				
Payload (kg)	Fuel economy (km/l)			
	Baseline	NYCC	OCTA	CSHVC
2,835	3.38 (8 mpg)	1.93 (4.6 mpg)	3.03 (7.2 mpg)	3.62 (8.6 mpg)

12% improvement case				
Payload (kg)	Fuel economy (km/l)			
	Baseline	NYCC	OCTA	CSHVC
2,835	3.79 (9 mpg)	2.17 (5.1 mpg)	3.39 (8 mpg)	4.05 (9.6 mpg)

3. Electric Truck Energy Efficiency

Like the diesel truck, electric truck efficiency can vary depending upon drive cycles as shown below. We estimate the electric truck efficiency using FASTSim (*4*) and the three drive cycles aforementioned. Simulation parameters are summarized in Table 2S. To reflect real-world vehicle operation data, we adjust the simulation result using the difference (75%) between simulation (33 mpgge) and field-test (25 mpgge) results on the New York Composite drive cycle (Figure 1S). We also consider ±20% efficiency uncertainty based on vehicle activity data (*5*). These estimates are higher (less efficient) than the simplistic estimate value (70% efficiency, oftentimes used as a fixed figure). For the baseline (drive cycle) case, we take the average of OCTA and CSHVC to follow the same pattern as the diesel truck.

TABLE 2S. Electric Truck Energy Efficiency

Simplistic estimate		
Parameters		Aggregate efficiency (MJ/km)
Battery capacity (kWh)	80[6]	2.3
Electric drive range (km)	160[6]	
Advertised electric drivetrain efficiency (MJ/km)	1.8	
DC-DC converter efficiency (%)	97[7]	
Inverter efficiency (%)	97[7]	
Tractive induction motor efficiency (%)	94[8]	
Charging/discharging efficiency (%)	90[9]	

Parameters for electric vehicle simulation			
Drag coefficient	0.5	Cargo mass (kg)	3,230 (full load)
Frontal area (m^2)	4.89	Electric motor power (kW)	120
Glider mass (kg)	4,260	Tire radius (m)	0.4
Wheel base (m)	3.9	Rolling resistance coefficient	0.01
2012 Nissan Leaf was used as a base platform with the parameters above adjusted to reflect the difference between passenger car and medium-duty truck, based on vehicle specifications (*6*) and vehicle test/activity data (*2*, *5*).			

Electric truck efficiency estimate					
		Drive Cycles			
		Baseline	NYCC	OCTA	CSHVC
Max (+20%)	mpgge	32.5	25.0	30.7	34.3
	MJ/km	2.3	3.0	2.5	2.2
Baseline (adjusted simulation result)	mpgge	27.1	20.9	25.6	28.6
	MJ/km	2.8	3.6	3.0	2.7
Min (-20%)	mpgge	21.7	16.7	20.5	22.9
	MJ/km	3.5	4.5	3.7	3.3

4. Natural Gas Life-Cycle GHG Emissions

For natural gas (NG) life-cycle GHG emissions in Table 2, we considered three categories of natural gas: domestic NG including pipeline imports from Mexico and Canada; overseas NG imported in the liquefied form (LNG); and synthetic and other types of NG, without carbon capture and sequestration.

TABLE 3S. Natural Gas: Life-Cycle GHG Emissions

Type of NG Consumed in U.S. Electricity Generation Sector[10]		Life-Cycle GHG Emissions (gCO_2e/MJ)[11]
Domestic NG	98.3%	156
Overseas LNG	1.4%	200
Synthetic NG (SNG) and other	0.2%	444
Weighted Total	100%	158

5. Vehicle production: Energy Use and GHG Emissions

For the diesel truck production energy use and GHG emissions, we utilized Carnegie Mellon University Green Design Institute's EIO-LCA database (*12*). We estimated GVW class 5 diesel truck production data (9 MJ/$ and 0.607 $kgCO_2e/\$$) by interpolation based on the curb weight differentials between an average passenger car and an average heavy-duty tractor-trailer. As the EIO-LCA data are based on 2002 vehicle prices, we estimated 2002 diesel truck purchase price to be approximately the same as the current price of $60,000 (*13*, *14*) using the consumer price index for new trucks (*15*).

TABLE 4S. Vehicle Manufacture Energy Use and GHG Emissions, Excluding Battery

Vehicle Type	**ICE Passenger Car**			**Electric Passenger Car**	**GVW Class 5 FedEx Diesel Truck**[a]
	Toyota Corolla[16]	VW Golf[17]	Ford Taurus[18]	VW Golf EV[17]	
Curb Weight (10^3 kg)	1.28	1.06	1.7	0.89	**4.4**
Vehicle Production Energy Use (10^3 MJ)	102	94.3	N/A	88.4	**540**
Vehicle Production GHG Emissions (10^3 $kgCO_2e$)	8.5	5.2	10	5.09	**36**
Vehicle Production (w/o Battery) Energy Use and GHG Emissions per Unit Curb Weight					
Energy Use (MJ/kg)	79.7	89	N/A	99.8	**120**
Avg. Energy Use (MJ/kg)	84.5 ± 6.4				
GHG Emissions ($kgCO_2e$/kg)	6.6	4.9	5.9	5.75	**8**
Avg. Emissions ($kgCO_2e$/kg)	5.82 ± 0.9				
Ratio of ICE and Electric (w/o Battery) Passenger Car Manufacturing					
Energy Use	1.18				
GHG Emissions	1.01				

[a] Estimated from passenger car and heavy-duty tractor-trailer EIO-LCA data (*12*). Detailed calculations are in Table 5S.

TABLE 5S. Energy Use and GHG Emissions for GVW Class 5 Diesel Truck Production

EIO-LCA: Vehicle Production	Passenger Car	Tractor	Trailer	Tractor-Trailer
Energy Use (MJ/$)	7.25[12]	9.76[12]	10.9[12]	10.3
GHG Emissions ($kgCO_2e$/$)	0.49[12]	0.64[12]	0.75[12]	0.70
Curb Weight (kg)	1,665[19]	7,650[19, 20]	5,290[19, 20]	6,470
Difference between Passenger Car and Heavy-Duty Tractor & Trailer				
(Δ Energy Use (MJ/$))/(Δ Curb Weight)	0.000641			
(Δ GHG Emissions ($kgCO_2e$/$))/(Δ Curb Weight)	0.000043			
Difference between Passenger Car and GVW Class 5 Diesel Truck				
Δ Curb Weight (kg)	2,740			
Δ Energy Use (MJ/$)	1.75			
Δ GHG Emissions ($kgCO_2e$/$)	0.117			
GVW Class 5 Diesel Truck Manufacture				
Energy Use (MJ/$)	9.0			
GHG Emissions ($kgCO_2e$/$)	0.607			
Year 2002 Diesel Truck Price (2002 $)	60,000			
Energy Use (10^3 MJ)	540			
GHG Emissions (10^3 $kgCO_2e$)	36.4			

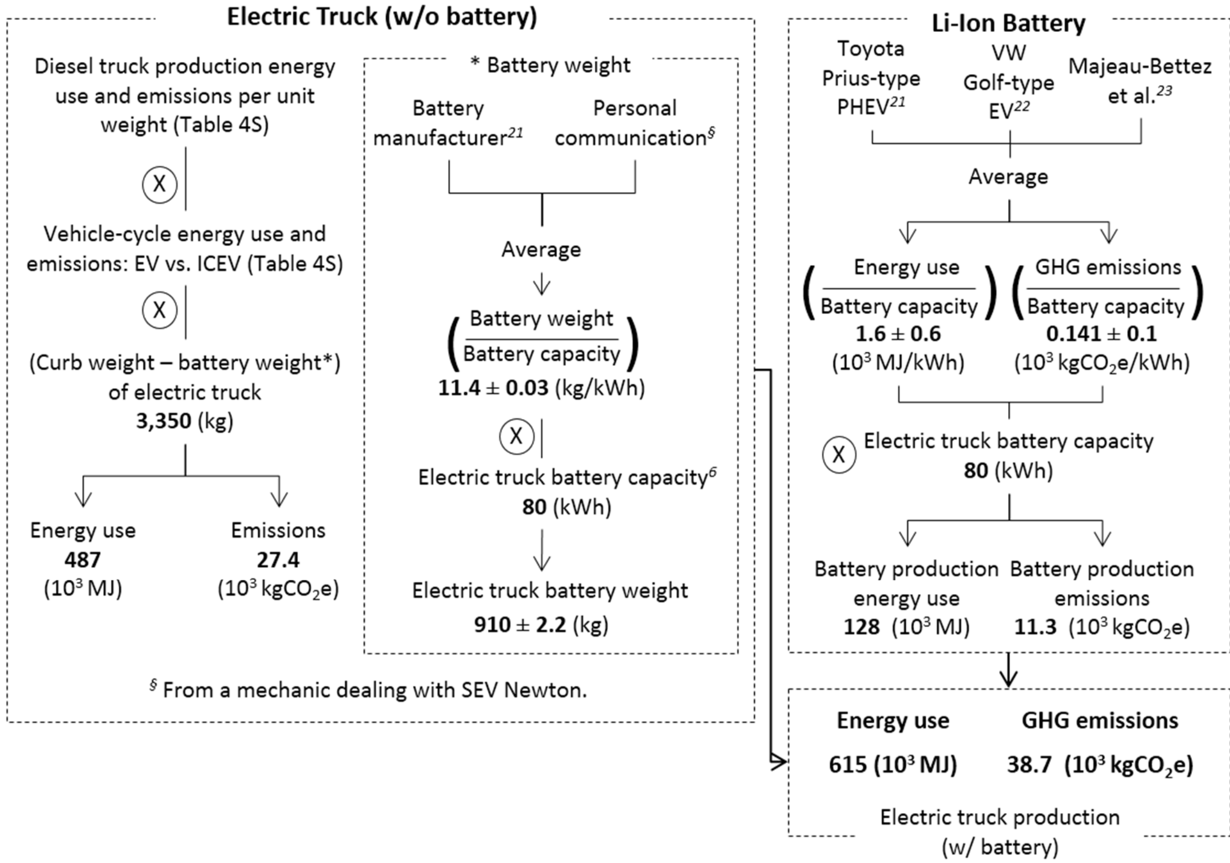


Figure 2S. Energy use and GHG emissions of electric truck (w/ Li-Ion battery) production.

6. End-of-Life Vehicle (ELV): Energy Use and GHG Emissions

According to the U.S. Environmental Protection Agency (EPA), 95% of automotive lead-acid batteries and 35% of the rubber from automobile and truck tires are recycled in the U.S. (*24*). In total, more than 75% of automotive materials are estimated to be reused, remanufactured, or recycled (*25*). Metals account for more than 75% of total vehicle weight (*25*), and about 95% of this weight is recycled (*26*). For ELV analysis, we only include metals recycling as illustrated in Figure 3S. About 20% of end-of-life engines (2.5 million out of 12.5 million end-of-life vehicles or engines per year) are remanufactured (*26*, *27*), and other parts could also be remanufactured or reused, but we assume that they will be ultimately recycled.

In terms of the automotive metals' embodied energy (direct energy content plus indirect energy required for mining, concentration, smelting, refining, transport, etc.) (*25*, *28*), net energy savings are about 30%, as shown in Table 6S. Here the net value includes the energy loss associated with the ELV collection, separation, recovery, etc. However, only 95% of metals are recovered through recycling processes. And the energy savings effect only applies to the substitution of raw material extraction and primary material processes which accounts for 86% of total vehicle-cycle energy use, as illustrated in Figure 3S and Table 6S. Thus, final energy savings from recycling is 25% of total vehicle-cycle energy use

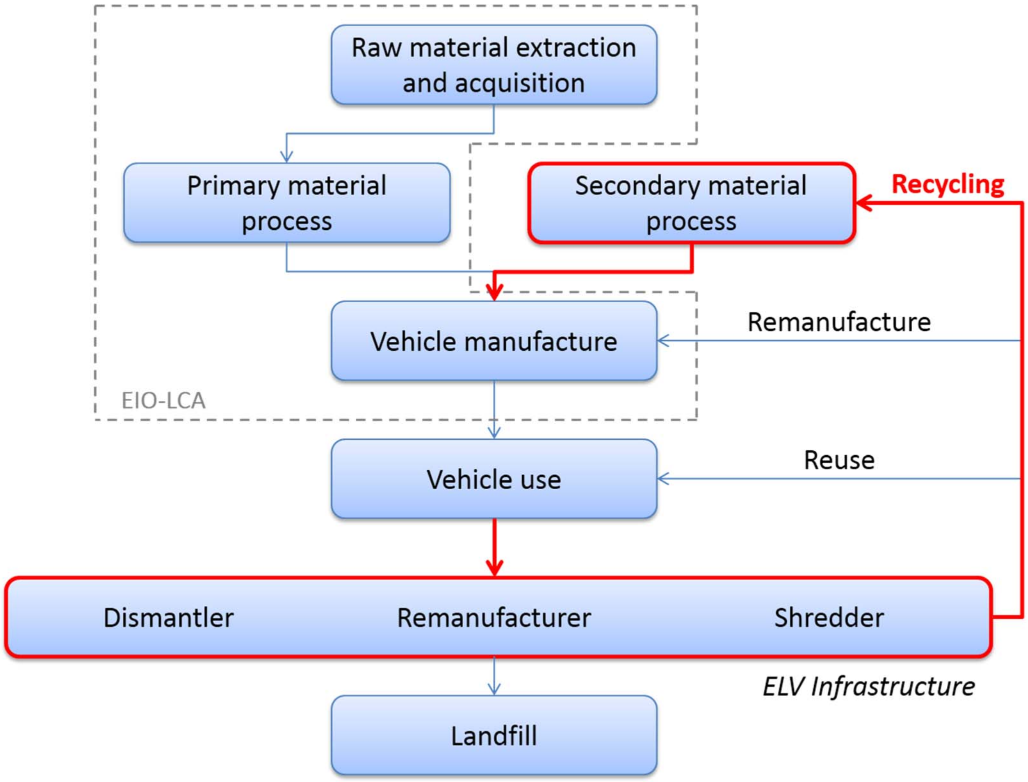


Figure 3S. Boundary of End-of-Life Vehicle Analysis

(excluding Li-Ion battery and EVSE). Likewise, GHG emissions reduction is estimated to be about 17%.

The estimated savings (25% energy use and 17% GHG emissions) above apply to non-battery vehicle production. The automotive Li-Ion battery is not currently recycled in the U.S. It is possible that auto makers or battery manufacturers will collect end-of-life Li-Ion batteries and send them to ELV infrastructure or electronics battery recycling facilities, and it has been reported that 19% life-cycle energy savings can be achieved from Li-Ion battery recycling (*29*). As experience with electric vehicle end-of-life management develops, further data will become available; in our study, the net energy use and GHG emissions savings from end-of-life Li-Ion batteries are assumed to be 0. We also assume that the EVSE recycling effect is negligible.

TABLE 6S. Net Energy and GHG Emissions Savings from ELV Recycling

Materials (Metals)	**% of embodied energy saved by recycling**	**Source**
Aluminum	82%	*25*
Iron, Carbon Steel, Other Ferrous	39%	
Stainless Steel	20%	
Copper	69%	
Zinc	38%	
Lead	97%	
MY 2009 Light-Duty Vehicles (LDV) Materials (Metals)	**% of weight**	*30*

Aluminum	8.3%	
Copper	1.6%	
Zinc	0.2%	
Lead	1.1%	
Other Ferrous	0.8%	
Iron	5.3%	
Regular Steel	38%	
High-Strength Steel	13%	
Stainless Steel	1.8%	
Weighted Total Net Energy Savings	**27%**	
Heavy-Duty Vehicle (HDV) Materials (Metals)	**% of weight**	*31*
Steel	51.3%	
Iron	13.0%	
Aluminum	14.3%	
Copper	1.0%	
Lead	0.5%	
Weighted Total Net Energy Savings	**33%**	
LDV and HDV Average Net Energy Savings	30%	-
ELV Metals Recovered	95%	*26*
Material Production and Extraction Proportion in Non-Recycling Vehicle-Cycle Energy Use	86%	*32*
Final Net Energy Savings of Total Vehicle-Cycle Energy Use (w/o Li-Ion Battery and EVSE)	**(30% x 95% x 86%)** **25%**	-
GHG Emissions Reduction per Vehicle Recycled	2.4 10^3 $kgCO_2e$	*33*
GHG Emissions of Average Passenger Car Production from Raw Material	7.9 10^3 $kgCO_2e$	Table 3S
Net GHG Emissions Savings	30%	
Material Production and Extraction Proportion in Non-Recycling Vehicle-Cycle GHG Emissions	57%	*31*
Final Net GHG Emissions Savings of Total Vehicle-Cycle GHG Emissions (w/o Li-Ion Battery and EVSE)	**(30% x 57%)** **17%**	-

7. Electric Truck Purchase Price

Battery capacity, vehicle size, curb weight, and/or payload can all affect electric truck purchase price. Specifications are often missing in price reports, increasing the price uncertainty. It should be noted that the SEV Newton has at least 16 different models varying by vehicle size, curb weight, payload, and battery capacity (Table 9S). Thus, it is important to identify the purchase price according to vehicle specifications. For the electric truck whose specifications are listed in Table 7S, we estimate the purchase price would range from $85,000 to $97,000, as illustrated in Tables 8S-10S.

TABLE 7S. Target Electric Truck Specification

Vehicle size	Overall length (m)	6.8
	Wheel base (m)	3.9
	Height w/o body (m)	2.4
	Width w/o body (m)	2.15
GVW (kg)		7,490
Curb weight (kg)		4,260
Payload (kg)		3,230
Battery capacity (kWh)		80

TABLE 8S. Reported Electric Truck Purchase Prices

Diesel Truck Price	Specifications	Electric Truck (SEV Newton) Price	Specifications	Source
$60,000	-	$85,000 - $90,000	-	*13*
$62,700	Overall length: 6.1 m GVW: 11,475 kg	$123,600	Overall length: 6.1 m GVW: 11,475 kg *Estimated* payload: 7,560 kg (Table 9S) *Estimated* battery capacity: 80 kWh (Table 9S)	*14*
-	-	Chassis and cab: $75,000 Battery: $25,000 (40 kWh) - $75,000 (120 kWh) *Estimated* battery price: 625 $/kWh	-	*34*
$60,000	-	$90,000	-	*35*
-	-	$150,000	Payload: 7,000 kg Range: 160 km Overall length: 9 m Box length: 6.5 m *Estimated* battery capacity: 120 kWh (Table 9S)	*36*

TABLE 9S. SEV Newton Electric Truck Specifications (*5*)

Wheel Base (mm)	Gross Vehicle Weight (kg)	Battery Pack Capacity (kWh)	Curb Weight (kg)	Payload (kg)	Deck Length (mm)	Overall Length (mm)	Overall Height (mm)	Overall Width (mm)
3,900	7,490	80	4,260	3,230	4,449	6,795	2,390	2,150
3,900	9,990	80	4,400	5,590	4,449	6,795	2,390	2,150
3,900	11,990	80	4,432	7,558	4,449	6,795	2,390	2,150
3,900	7,490	120	4,728	2,762	4,449	6,795	2,390	2,150
3,900	9,990	120	4,818	5,172	4,449	6,795	2,390	2,150
3,900	11,990	120	4,900	7,090	4,449	6,795	2,390	2,150
4,500	7,490	80	4,269	3,221	5,434	7,795	2,390	2,150
4,500	9,990	80	4,390	5,600	5,434	7,795	2,390	2,150
4,500	11,990	80	4,482	7,508	5,434	7,795	2,390	2,150
4,500	7,490	120	4,737	2,753	5,434	7,795	2,390	2,150
4,500	9,990	120	4,858	5,132	5,434	7,795	2,390	2,150
4,500	11,990	120	4,950	7,040	5,434	7,795	2,390	2,150
5,100	9,990	80	4,456	5,534	6,449	8,795	2,390	2,150
5,100	11,990	80	4,591	7,399	6,449	8,795	2,390	2,150
5,100	9,990	120	4,924	5,066	6,449	8,795	2,390	2,150
5,100	11,990	120	5,059	6,931	6,449	8,795	2,390	2,150

TABLE 10S. Price Estimate of Target SEV Newton w/ Specifications in Table 7S

Non-battery (chassis & cab) vehicle price *per unit payload* (Table 8S)	$9.9
Non-battery (chassis & cab) vehicle price *per unit GVW* (Table 8S)	$6.3
Payload (kg)	**GVW (kg)**
3,230	7,490
Payload-based non-battery part	**GVW-based non-battery part**
$32,000	$47,000
80 kWh battery cost	
$50,000	
GVW-based SEV Newton Price	**Payload-based SEV Newton Price**
$82,000 (lower than reported)	$97,000
Min	**Max**
$85,000 (lowest among the reported - Table 8S)	$97,000

8. Electric Truck Li-Ion Battery Lifetime

Battery replacement can be very significant in terms of the total cost of ownership (TCO), given the expensive automotive Li-Ion battery price. Battery replacement is mainly determined by battery cycle life along with potential mechanical or chemical failure. Battery cycle life usually refers to the point when battery capacity reaches 80% of the original capacity after a certain number of recharging activities (cycles). As shown in Table 11S, the maximum expected cycles (4,800 – 9,600 depending upon VKT demand and recharging frequency) fall within the estimate of cycle life (more than 10,000).

TABLE 11S. Electric Truck Battery Cycle Life Estimation

Battery capacity		80	kWh
Battery lifetime (*37*, *38*)	Cycle life at 100% depth of discharge (DoD)	2,800	cycles
	Range per full charge	160	km
	For 2,800 cycles	448,000	km
Vehicle lifetime VKT in our study		240,000	km
Electric truck energy efficiency (Table 2)		0.78	kWh/km

Daily VKT (km)	Recharging frequency per day	VKT between charges	DoD (%) with 0.78 kWh/km efficiency	Estimated cycle life based on 200 cycle life gain per 1% DoD decrease (*39*)	Cycles (total recharging frequency) for 20 years
48	1	48	47	10,000	4,800
	2	24	23	> 10,000	9,600
96	1	96	> 100	-	4,800
	2	48	47	10,000	9,600

9. Electric Truck Li-Ion Battery Price

Our estimate of current battery price is 625 $/kWh (*40*). There has been a wide range of automotive Li-Ion battery price estimates (Figure 4S). Battery prices are changing rapidly (*40*, *41*), and thus some of the projections in Figure 4S may be outdated.

The projections in Figure 4S are for passenger car HEVs, PHEVs, or EVs, which have a higher power-to-energy ratio than the electric truck. The SEV Newton has a very low power-to-energy ratio (1 – 1.5 W/Wh) and also a very high battery capacity (80 – 120 kWh) compared to passenger car PHEV (e.g., GM Volt – 6.94 W/Wh, 16 kWh) or EV (e.g., Nissan Leaf – 3.33 W/Wh, 24 kWh) (*5*, *42*, *43*). As shown in Figure 5S, battery prices ($/kWh) increase with the power-to-energy ratio (W/Wh).

Figure 5S indicates that batteries with power-to-energy ratios in the range of 1 to 6 have prices in the range of 200-300 $/kWh. The average is about 230 $/kWh, which we use as an estimate of the 2020 electric truck battery price. It should be noted that the MIT report assumes high production volume (100,000 electric vehicle batteries per year) for the price projection; according to the Energy Information Administration projection (*44*), annual electric vehicle sales will reach 100,000 in 2016 – 2018.

We do not incorporate the resale value of Li-ion truck battery packs, because resale markets do not yet exist for them. After their useful life in vehicles, batteries could be resold to utilities for use as back-up power for solar and wind power to store energy and regulate frequency. This would reduce the life cycle cost of electric delivery trucks.

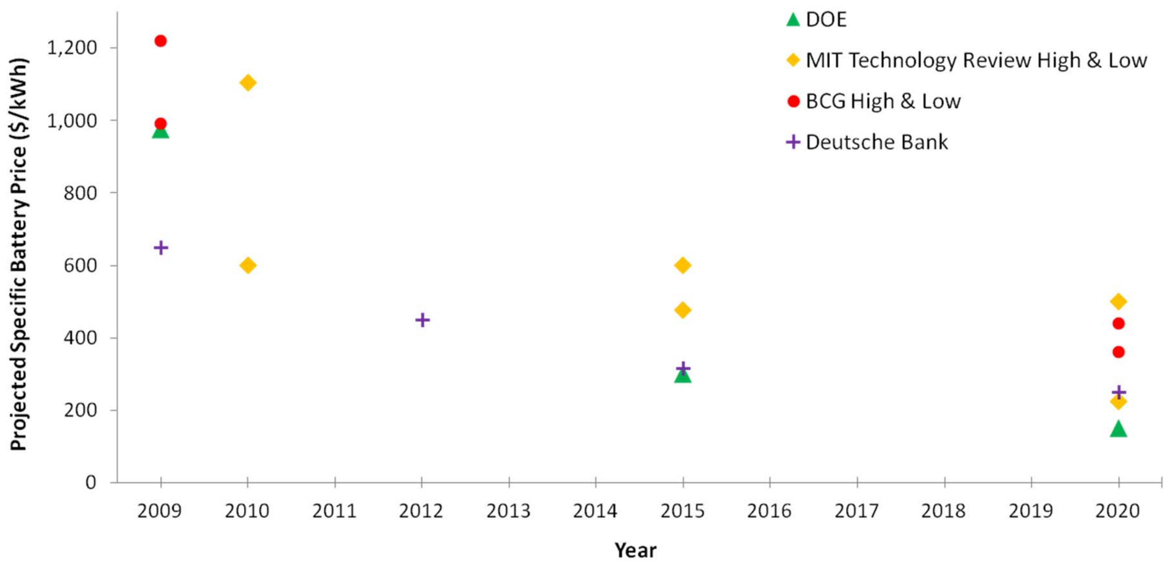


Figure 4S. Battery price projections. DOE: Ref *45*; MIT Technology Review High & Low: Ref *46*; The Boston Consulting Group (BCG) High & Low: Ref *47*; Deutsche Bank: Ref *40*.

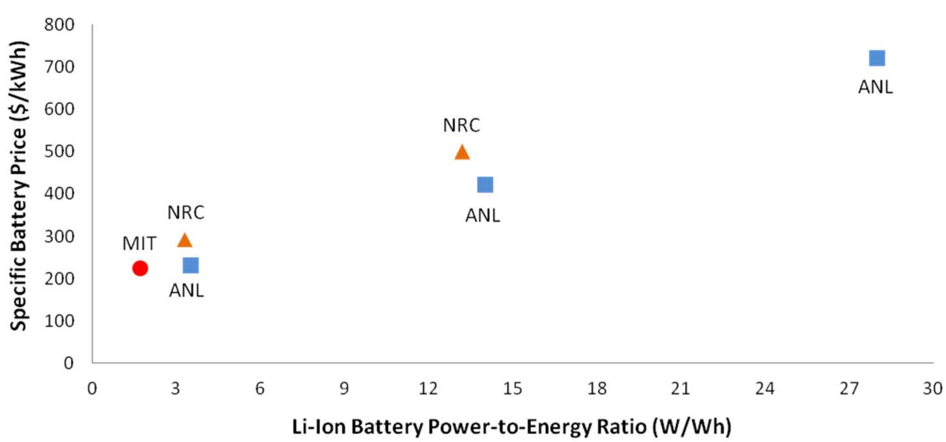


Figure 5S. Specific battery cost variation according to power-to-energy ratio. Argonne National Laboratory (ANL): Ref *48*; MIT: Ref *49*; National Research Council (NRC): Ref *50*.

10. Electric Vehicle Supply Equipment (EVSE) Price

We assume that electric truck fleet operators will use either EVSE Level 1 or Level 2. Since EVSE Level 1 comes with the electric truck, there is no cost associated with EVSE Level 1. EVSE Level 2 current and future price estimates are listed in Table 12S.

TABLE 12S. Current and Future EVSE Level 2 Price

Electric Vehicle Supply Equipment (EVSE) Level 2 Price		**Installation**		**Source**
Min	Max	Min	Max	
1,000	7,000	860	7,400	*51*
2,614	6,353	500	7,000	*52*
1,600		2,000	10,000	*53*
-		316	4,065	*54*
4,213				*55*
Total: EVSE Level 2 + Installation				
Min	1,860	Max	14,400	
2017 (after 6 years) Price (50% of 2011 price)				
Min	930	Max	7,200	

11. Diesel Fuel and Electricity Price

Figure 6S shows the four diesel fuel price scenarios and two electricity price scenarios that we used for the TCO calculation.

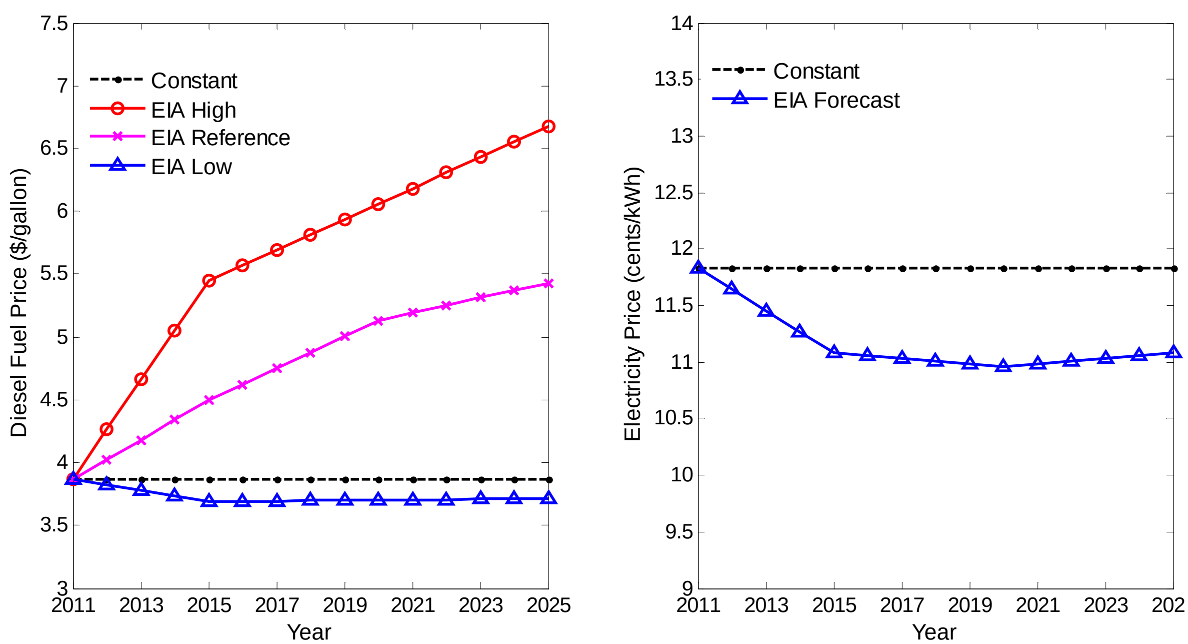


Figure 6S. Diesel fuel and electricity price projections, adapted from (*9*, *56, 57*), with 2011 prices as initial values.

12. Power Generation Mix

Table 13S. State-by-State and U.S. Average Electricity Generation Mix without Imports from Other States or Abroad: 2011-2012 and 2025 (adapted from *58*).

State	Coal	Natural Gas	Nuclear	Hydroelectric Conventional	Petroleum	Other	
						Wind	Non-Wind
AK	9.0%	53.4%	0.0%	23.8%	13.4%	0.2%	0.1%
AL	32.9%	33.5%	25.6%	5.9%	0.1%	0.0%	2.0%
AR	45.9%	22.9%	23.5%	4.9%	0.1%	0.0%	2.8%
AZ	38.7%	23.0%	29.4%	8.1%	0.0%	0.3%	0.5%
CA	1.0%	48.6%	15.2%	18.5%	0.3%	4.7%	11.8%
CO	65.3%	20.3%	0.0%	4.3%	0.0%	10.0%	0.0%
CT	1.0%	44.1%	49.0%	1.2%	0.4%	0.0%	4.3%
DC	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
DE	19.8%	75.9%	0.0%	0.0%	0.5%	0.1%	3.7%
FL	22.1%	64.1%	9.2%	0.1%	1.2%	0.0%	3.4%
GA	42.5%	25.7%	26.9%	2.4%	0.4%	0.0%	2.0%
HI	14.2%	0.0%	0.0%	1.1%	74.4%	3.4%	6.9%
IA	64.1%	2.7%	9.2%	2.1%	0.2%	21.3%	0.3%
ID	0.5%	8.6%	0.0%	77.9%	0.0%	9.4%	3.7%
IL	43.1%	4.4%	48.4%	0.1%	0.0%	3.5%	0.4%
IN	83.3%	10.5%	0.0%	0.3%	0.1%	2.9%	2.8%
KS	68.4%	6.5%	15.3%	0.0%	0.1%	9.7%	0.0%
KY	92.4%	2.6%	0.0%	2.9%	1.7%	0.0%	0.4%
LA	21.5%	53.6%	16.3%	1.0%	3.9%	0.0%	3.8%
MA	9.1%	67.9%	14.6%	2.9%	0.5%	0.1%	4.8%
MD	46.1%	8.6%	35.0%	6.3%	0.4%	0.9%	2.7%
ME	0.3%	44.7%	0.0%	24.8%	1.0%	5.1%	24.1%
MI	50.6%	16.7%	28.2%	1.6%	0.3%	0.5%	2.1%
MN	48.0%	9.5%	22.5%	2.2%	0.1%	13.9%	3.9%
MO	80.8%	5.7%	10.5%	1.3%	0.1%	1.4%	0.3%
MS	16.7%	64.5%	15.8%	0.0%	0.1%	0.0%	2.9%
MT	47.5%	0.3%	0.0%	44.9%	1.6%	4.4%	1.2%
NC	47.8%	12.1%	34.5%	3.6%	0.2%	0.0%	1.8%
ND	77.2%	0.1%	0.0%	7.4%	0.1%	15.0%	0.2%
NE	69.6%	2.0%	19.7%	5.2%	0.1%	3.3%	0.2%
NH	9.1%	35.3%	40.5%	8.3%	0.3%	0.6%	6.1%
NJ	5.0%	40.4%	52.2%	0.0%	0.1%	0.0%	2.3%
NM	69.1%	23.5%	0.0%	0.8%	0.1%	6.0%	0.5%
NV	13.3%	69.5%	0.0%	7.6%	0.0%	0.0%	9.6%
NY	5.8%	38.7%	30.6%	20.0%	0.7%	2.2%	2.0%

OH	74.0%	12.2%	11.3%	0.3%	1.0%	0.4%	0.8%
OK	42.7%	45.8%	0.0%	2.8%	0.0%	8.4%	0.3%
OR	4.4%	14.3%	0.0%	70.9%	0.0%	9.2%	1.2%
PA	41.7%	20.8%	33.5%	1.3%	0.2%	0.9%	1.7%
RI	0.0%	98.1%	0.0%	0.0%	0.1%	0.0%	1.6%
SC	31.9%	12.9%	51.8%	1.9%	0.1%	0.0%	1.3%
SD	21.4%	2.1%	0.0%	52.0%	0.1%	24.4%	0.0%
TN	46.6%	5.8%	35.1%	11.6%	0.2%	0.1%	0.6%
TX	34.0%	47.8%	9.1%	0.3%	0.2%	7.4%	1.3%
UT	79.3%	15.0%	0.0%	2.6%	0.1%	1.7%	1.3%
VA	26.4%	30.5%	38.9%	1.8%	0.7%	0.0%	1.8%
VT	0.0%	0.0%	71.7%	20.8%	0.0%	0.9%	6.6%
WA	3.3%	4.3%	5.4%	79.6%	0.0%	5.6%	1.9%
WI	56.5%	14.3%	19.5%	4.4%	0.8%	2.2%	2.2%
WV	95.6%	0.3%	0.0%	2.1%	0.2%	1.7%	0.0%
WY	85.5%	1.1%	0.0%	2.6%	0.1%	10.0%	0.6%
US-TOTAL 2011-2012	**39.8%**	**26.9%**	**19.3%**	**7.9%**	**0.6%**	**3.2%**	**2.3%**
US-TOTAL 2025	**39.2%**	**25.0%**	**20.1%**	**7.6%**	**0.6%**	**4.0%**	**3.4%**

13. Equations for Energy Consumption, GHG Emissions, and TCO Calculations

13.1. Energy Consumption

For the electric truck:

$$EC_{ET} = \frac{1}{\left\{\sum_i \left[\frac{\eta_{PP_i}}{1+\left(\frac{\eta_{PP_i}}{EPR_i}\right)} \times GM_i\right]\right\} \times \eta_{TM} \times \eta_{TTW_{ET}} \times PL_{ET}} + \left\{\frac{EC_{VM_{ET}}}{VKT_{LF} \times PL_{ET}}\right\}$$

$$+ \left\{\frac{EC_B + EC_{EVSE} + EC_{B_R} + EC_{EVSE_R}}{\frac{1}{2} \times VKT_{LF} \times PL_{ET}}\right\} + \left\{\frac{EC_{ELV_{ET}}}{VKT_{LF} \times PL_{ET}}\right\}$$

Table 14S. Electric Truck: Energy Consumption Parameters

Parameter	Description	Unit	Value (Baseline – Table 2)	
i	i-th generation fuel	-	-	Table 2
η_{PP_i}	Power plant's electricity generation efficiency	%	-	Section 2.3
EPR_i	Energy payback ratio	%	-	
GM_i	Generation mix	%	-	Table 2
η_{TM}	Electric grid transmission efficiency	%	93	
$\eta_{TTW_{ET}}$	TTW efficiency of the electric truck	km/MJ	0.357	
PL_{ET}	Payload of the electric truck	t	3.23	Table 1
Total operational energy consumption of the electric truck		MJ/t·km	2.34	Table 2
$EC_{VM_{ET}}$	Energy consumption for vehicle (electric truck) manufacture	MJ	487,000	Figure 2S
EC_B	Energy consumption for Li-Ion battery production		128,000	
EC_{EVSE}	Energy consumption for EVSE production		4,290	Section 2.4
EC_{B_R}	Energy consumption for Li-Ion battery replacement		128,000	Figure 2S
EC_{EVSE_R}	Energy consumption for EVSE replacement		4,290	Section 2.4
$EC_{ELV_{ET}}$	Net energy consumption of end-of-life vehicle recycling of the electric truck		-122,000	
VKT_{LF}	Lifetime VKT	km	240,000	Section 2.5
$\frac{1}{2} \times VKT_{LF}$	Li-Ion battery and EVSE are assumed to be replaced after 120,000 km in energy use model	km	120,000	-
$\boldsymbol{EC_{ET}}$	**Total life-cycle energy consumption of the electric truck**	**MJ/t·km**	**3.49**	**-**

For the diesel truck:

$$EC_{DT} = \left\{\frac{1}{\eta_{UP} \times \eta_{TTW_{DT}} \times PL_{DT}}\right\} + \left\{\frac{EC_{VM_{DT}} + EC_{ELV_{DT}}}{VKT_{LF} \times PL_{DT}}\right\}$$

Table 15S. Diesel Truck: Energy Consumption Parameters

Parameter	**Description**	**Unit**	**Value (Baseline – Table 2)**	
η_{UP}	Aggregate upstream efficiency	%	87.3	Table 2
$\eta_{TTW_{DT}}$	TTW efficiency of the diesel truck	km/MJ	0.093	
PL_{DT}	Payload of the diesel truck	t	2.86	Table 1
Total operational energy consumption of the diesel truck		MJ/t·km	4.3	Table 2
$EC_{VM_{DT}}$	Energy consumption for vehicle (diesel truck) manufacture	MJ	540,000	Table 3S
$EC_{ELV_{DT}}$	Net energy consumption of end-of-life vehicle recycling of the diesel truck		-135,000	Section 2.4
$\boldsymbol{EC_{DT}}$	**Total life-cycle energy consumption of the diesel truck**	**MJ/t·km**	**4.9**	**-**

13.2. GHG Emissions

For the electric truck:

$$GHG_{ET} = \frac{\{\sum_i [GHG_{LC_i} \times GM_i]\}}{\eta_{TM} \times \eta_{TTW_{ET}} \times PL_{ET}} + \left\{\frac{GHG_{VM_{ET}}}{VKT_{LF} \times PL_{ET}}\right\} + \left\{\frac{GHG_B + GHG_{EVSE} + GHG_{B_R} + GHG_{EVSE_R}}{\frac{1}{2} \times VKT_{LF} \times PL_{ET}}\right\} + \left\{\frac{GHG_{ELV_{ET}}}{VKT_{LF} \times PL_{ET}}\right\}$$

Table 16S. Electric Truck: GHG Emissions Parameters

Parameter	Description	Unit	Value (Baseline – Table 2)	
i	i-th generation fuel	-	-	Table 2
GHG_{LC_i}	GHG emissions from power plant's electricity generation	$kgCO_2e/MJ_e$	-	
GM_i	Generation mix	%	-	
η_{TM}	Electric grid transmission efficiency	%	93	
$\eta_{TTW_{ET}}$	TTW efficiency of the electric truck	km/MJ_e	0.357	
PL_{ET}	Payload of the electric truck	t	3.23	Table 1
Total operational GHG Emissions of the electric truck		$kgCO_2e/t{\cdot}km$	0.15	Table 2
$GHG_{VM_{ET}}$	GHG emissions from vehicle (electric truck) manufacture	$kgCO_2e$	27,400	Figure 2S
GHG_B	GHG emissions from Li-Ion battery production		11,300	
GHG_{EVSE}	GHG emissions from EVSE production		250	Section 2.4
GHG_{B_R}	GHG emissions from Li-Ion battery replacement		11,300	Figure 2S
GHG_{EVSE_R}	GHG emissions from EVSE replacement		250	Section 2.4
$GHG_{ELV_{ET}}$	Net GHG emissions from end-of-life vehicle recycling of the electric truck		-4,660	
VKT_{LF}	Lifetime VKT	km	240,000	Section 2.5
$\frac{1}{2} \times VKT_{LF}$	Li-Ion battery and EVSE are assumed to be replaced after 120,000 km in GHG emissions model	km	120,000	-
$\boldsymbol{GHG_{ET}}$	**Total life-cycle GHG emissions from the electric truck**	**$kgCO_2e/t{\cdot}km$**	**0.24**	**-**

For the diesel truck:

$$GHG_{DT} = \frac{GHG_{LC_D}}{\eta_{TTW_{DT}} \times PL_{DT}} + \left\{\frac{GHG_{VM_{DT}} + GHG_{ELV_{DT}}}{VKT_{LF} \times PL_{DT}}\right\}$$

Table 17S. Diesel Truck: GHG Emissions Parameters

Parameter	Description	Unit	Value (Baseline – Table 2)	
GHG_{LC_D}	Life-cycle GHG emissions of diesel fuel	$kgCO_2e/MJ$	0.09	Table 2
$\eta_{TTW_{DT}}$	TTW efficiency of the diesel truck	km/MJ	0.093	
PL_{DT}	Payload of the diesel truck	t	2.86	Table 1
Total operational energy consumption of the diesel truck		$kgCO_2e/t{\cdot}km$	0.34	Table 2
$GHG_{VM_{DT}}$	GHG emissions from vehicle (diesel truck) manufacture	$kgCO_2e$	36,000	Table 3S
$GHG_{ELV_{DT}}$	Net GHG emissions from end-of-life vehicle recycling of the diesel truck		-6,100	Section 2.4
$\boldsymbol{GHG_{DT}}$	**Total life-cycle GHG emissions from the diesel truck**	**$kgCO_2e/t{\cdot}km$**	**0.38**	**-**

13.3. TCO (for baseline case in Figure 4)

$$TCO_{ij} = P_{P_{ij}} + \left\{\frac{P_{F_{ij}} \times VKT}{\eta_{PT_i}}\right\} + \{C_{M_i} \times VKT\} + \{P_{B_{ij}} \times BC_i \times R_{B_{ij}}\} + \{P_{EVSE_{ij}} \times L_{EVSE_i} \times R_{EVSE_{ij}}\}$$

Table 18S. TCO Parameters

Parameter	Description	Unit	Value	
			Diesel truck $i = 0$	**Electric Truck** $i = 1$
j	j-th year	-	from 0 to 11 – 20 $j = 0$: only for upfront costs (see Section 2.5)	
TCO_{ij}	Total cost of ownership for j-th year	$	-	-
$P_{P_{ij}}$	Purchase price of the GVW class 5 truck	$	60,000	85,000 – 97,000
			0 when $j \neq 0$	
$P_{F_{ij}}$	Fuel price	$/gal	4 scenarios (Figure 5S)	-
		$/kWh	-	2 scenarios (Figure 5S)
VKT	Annual vehicle kilometers traveled (travel demand)	km	48 – 96 (x 20 days per month x 12 months)	
η_{PT_i}	Powertrain energy efficiency	km/gal	12.8 – 14.3	-
		km/kWh	-	1.03 – 1.54
C_{M_i}	Maintenance cost per unit distance traveled	$/km	0.139	0.035 – 0.069
$P_{B_{ij}}$	Battery price	$/kWh	0	625 in 2011 230 in 2020
BC_i	Battery capacity	kWh	-	80
$R_{B_{ij}}$	Battery replacement	-	-	0 or 1 ($R_{B_{ij}} = 1$ for randomly selected j between 6 – 10: Section 2.5)

$P_{EVSE_{ij}}$	EVSE price	$	0	0 for Level 1 1,860 – 14,400 in 2011 1,000 – 7,000 in 2017 for Level 2
L_{EVSE_i}	EVSE Level	-	-	Level 1 or 2
$R_{EVSE_{ij}}$	EVSE replacement	-	-	0 or 1 ($R_{B_{ij}} = 1$ for $j = 16$ for Level 1 and $j = 7$ for Level 2 (Section 2.5)

14. Sensitivity Analysis for Energy Consumption and GHG Emissions

We consider that the energy consumption and GHG emissions calculations are basically linear, with limited interaction and/or non-linearity. As shown in the formula below, we increase by 5% each of the independent variables, one at a time, to evaluate the difference in the total life-cycle energy consumption and GHG emissions. Even though we assumed no interaction between independent variables, changing any of the electricity generation fuel's proportion/contribution entails inevitable adjustment of the other generation fuels so that the total remains 100%. Thus, when we change one of the generation fuel's contribution (e.g., from 10% to 10.5%) for sensitivity analysis, we decrease the other five generation fuels' contributions (e.g., 0.5% x 0.2%) evenly and proportionally to the difference. Also, the 5% increase doesn't apply to battery replacement; the replacement is either 0 or 1.

$$Sensitivity\ (\%) = \left| \frac{[f_{diesel}(x) - f_{electric}(x)]|_{x=(x_0+5\%\times x_0)} - [f_{diesel}(x) - f_{electric}(x)]|_{x=x_0}}{[f_{diesel}(x) - f_{electric}(x)]|_{x=x_0}} \right|$$

Table 19S. Energy Use and GHG Emissions Sensitivity Analysis Result (Sorted from Largest to Smallest)

Independent Variables	**Energy Use**	**Independent Variables**	**GHG**
Battery Replacement	82%	Battery Replacement	34%
DT TTW Energy Consumption	53%	DT TTW Energy Consumption	20%
Diesel Fuel Upstream Efficiency	51%	Diesel Fuel LC GHG Emissions	20%
ET TTW Energy Consumption	41%	ET TTW Energy Consumption	12%
Transmission Efficiency	39%	Transmission Efficiency	12%
Coal Power Plant Efficiency	12%	Coal LC GHG Emissions	9%
NG Power Plant Efficiency	10%	Coal Generation Mix	6%
Battery Production Energy Use	8%	Battery Production GHG Emissions	3%
DT Manufacture Energy Use	7%	NG LC GHG Emissions	3%
Hydro Power Plant Efficiency	7%	DT Manufacture GHG Emissions	3%
Coal Generation Mix	7%	Nuclear Generation Mix	2%
Nuclear Power Plant Efficiency	6%	ET Manufacture GHG Emissions	2%
ET Manufacture Energy Use	6%	NG Generation Mix	1%
Hydro Generation Mix	4%	Hydro Generation Mix	1%
Nuclear Generation Mix	3%	Other Generation Mix	1%
Other Power Plant Efficiency	3%	Recycling	< 1%
NG Generation Mix	1%	Nuclear LC GHG Emissions	
NG EPR	1%	Petroleum LC GHG Emissions	
Coal EPR	1%	Petroleum Generation Mix	
Recycling	< 1%	EVSE GHG Emissions	
Petroleum Power Plant Efficiency		Other LC GHG Emissions	
EVSE Energy Use		Hydro LC GHG Emissions	
Nuclear EPR		Coal EPR	
Petroleum Generation Mix		NG EPR	

Other Generation Mix		Nuclear EPR	
Other EPR		Hydro EPR	
Hydro EPR		Petroleum EPR	
Petroleum EPR		Other EPR	
Coal LC GHG Emissions		Coal Power Plant Efficiency	
NG LC GHG Emissions		NG Power Plant Efficiency	
Nuclear LC GHG Emissions		Nuclear Power Plant Efficiency	
Hydro LC GHG Emissions		Hydro Power Plant Efficiency	
Petroleum LC GHG Emissions		Petroleum Power Plant Efficiency	
Other LC GHG Emissions		Other Power Plant Efficiency	
ET Manufacture GHG Emissions		ET Manufacture Energy Use	
Battery Production GHG Emissions		Battery Production Energy Use	
EVSE GHG Emissions		EVSE Energy Use	
Diesel Fuel LC GHG Emissions		Diesel Fuel Upstream Efficiency	
DT Manufacture GHG Emissions		DT Manufacture Energy Use	

15. Regression Analysis Result for TCO Sensitivity Analysis

$$
\begin{aligned}
NPV = \ & \beta_0 + \beta_1 \times \{Fuel\ Price\ Scenario \times VKT \times Fuel\ Consumption\} \\
& + \beta_2 \times \{Battery\ Replacement\ Scenario \times Battery\ Price\} \\
& + \beta_3 \times \{EVSE\ Level \times EVSE\ Price\} + \beta_4 \times Discount\ Rate \\
& + \beta_5 \times Purchase\ Price\ Differential + \beta_6 \times Electric\ Powertrain\ Efficiency \\
& + \beta_7 \times Maintenance\ Cost\ Differential + \beta_8 \times Electricity\ Price\ Scenario
\end{aligned}
$$

Table 20S. Linear Regression Result

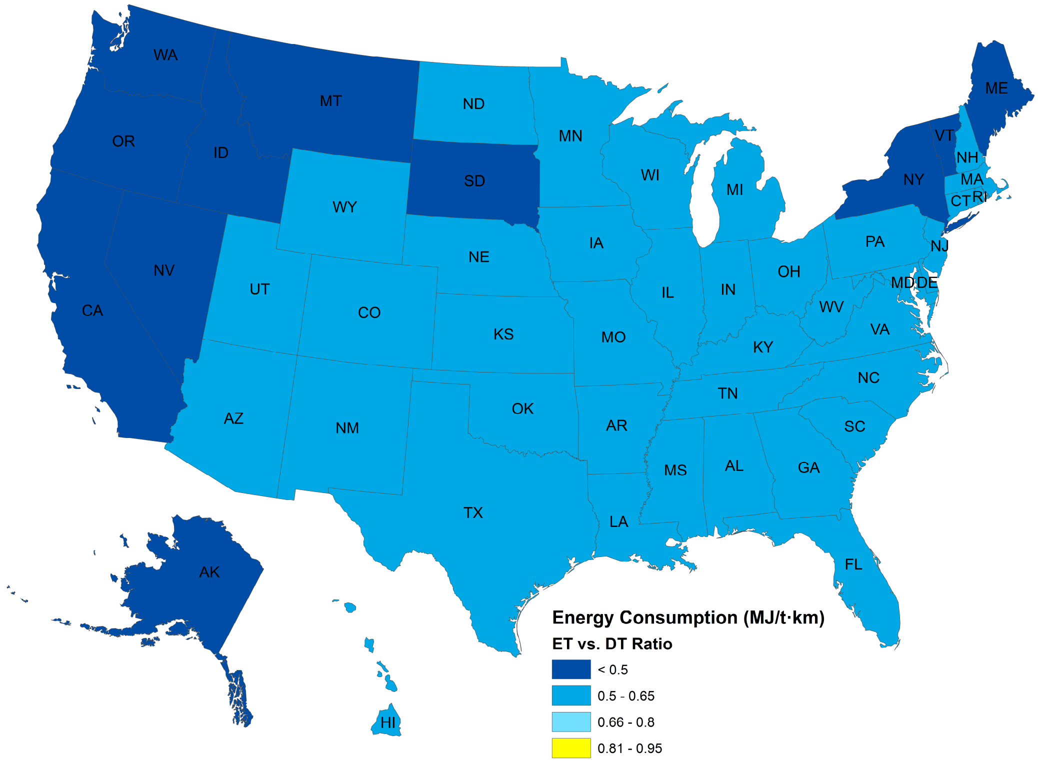
(Number of samples: 10^{5})	Coefficient		Standard Error	*Standardized*		
				Coefficient	*t*	$Pr(>\lvert t \rvert)$
Intercept	β_0	2.6x10^{4}	1.9x10^{2}	0	1.4x10^{2}	1
Fuel Price Scenario, VKT, and Fuel Consumption	β_1	4.4x10^{0}	7.4x10^{-3}	**0.5**	6.0x10^{2}	<2x10^{-16}[b]
Battery Replacement Scenario and Battery Price	β_2	-2.1x10^{1}	3.6x10^{-2}	**-0.48**	-5.8x10^{2}	
EVSE Level and EVSE Price	β_3	-6.4x10^{-1}	1.2x10^{-3}	**-0.44**	-5.2x10^{2}	
Discount Rate	β_4	-2.1x10^{5}	4.1x10^{2}	**-0.42**	-5.0x10^{2}	
Purchase Price Differential[a]	β_5	1.0x10^{0}	3.4x10^{-3}	**0.25**	3.0x10^{2}	
Electric Powertrain Efficiency	β_6	1.0x10^{4}	8.0x10^{1}	**0.1**	1.2x10^{2}	
Maintenance Cost Differential[a]	β_7	1.3x10^{5}	1.2x10^{3}	**0.09**	1.1x10^{2}	
Electricity Price Scenario	β_8	-6.1x10^{2}	2.4x10^{1}	**-0.02**	-2.6x10^{1}	
R^2	0.93					
Adjusted R^2	0.93					
F-Statistic	1.66x10^{5}					

[a] Difference between the diesel truck and electric truck. [b] At a 5% significance level.

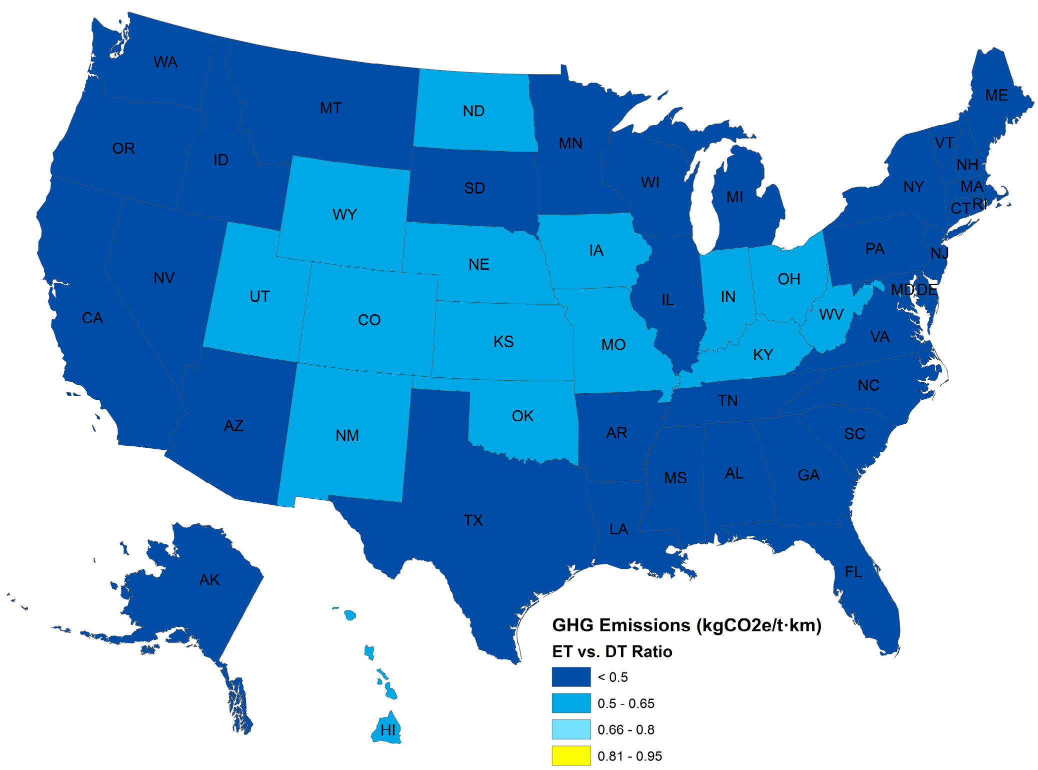
16. Electricity Transmission and Distribution Efficiency (*59*)

	(Million Kilowatthours)	2004	2005	2006	2007	2008	2009	2010
Supply	Electric Utilities	2,505,231	2,474,846	2,483,656	2,504,131	2,475,367	2,372,776	2,471,632
	Independent Power Producers	1,118,870	1,246,971	1,259,062	1,323,856	1,332,068	1,277,916	1,338,712
	Combined Heat and Power, Electric	184,259	180,375	165,359	177,356	166,915	159,146	162,042
	Electric Power Sector Generation Subtotal	3,808,360	3,902,192	3,908,077	4,005,343	3,974,349	3,809,837	3,972,386
	Combined Heat and Power, Commercial	8,270	8,492	8,371	8,273	7,926	8,165	8,592
	Combined Heat and Power, Industrial	153,925	144,739	148,254	143,128	137,113	132,329	144,082
	Industrial and Commercial Generation Subtotal	162,195	153,231	156,625	151,401	145,039	140,494	152,674
	Total Net Generation	3,970,555	4,055,423	4,064,702	4,156,745	4,119,388	3,950,331	4,125,060
	Total International Imports	34,210	43,929	42,691	51,396	57,019	52,191	45,083
	Total Supply	4,004,765	4,099,352	4,107,394	4,208,140	4,176,407	4,002,522	4,170,143
Disposition	Full Service Providers	3,317,635	3,412,721	3,438,337	3,468,018	3,433,681	3,288,951	3,364,990
	Energy-Only Providers	222,027	237,055	219,185	282,538	285,714	295,226	379,277
	Facility Direct Retail Sales	7,817	11,193	12,397	14,004	13,567	12,689	10,226
	Total Electric Industry Retail Sales	3,547,479	3,660,969	3,669,919	3,764,561	3,732,962	3,596,865	3,754,493
	Direct Use	168,470	150,016	146,927	125,670	132,197	126,938	134,554
	Total International Exports	22,898	19,151	24,271	20,144	24,198	18,138	19,106
	Estimated Losses	265,918	269,217	266,277	297,766	287,050	260,581	261,990
	Total Disposition	4,004,765	4,099,352	4,107,394	4,208,140	4,176,407	4,002,522	4,170,143
	Transmission and Distribution Loss (%)	**6.9%**	**6.8%**	**6.7%**	**7.3%**	**7.1%**	**6.7%**	**6.5%**

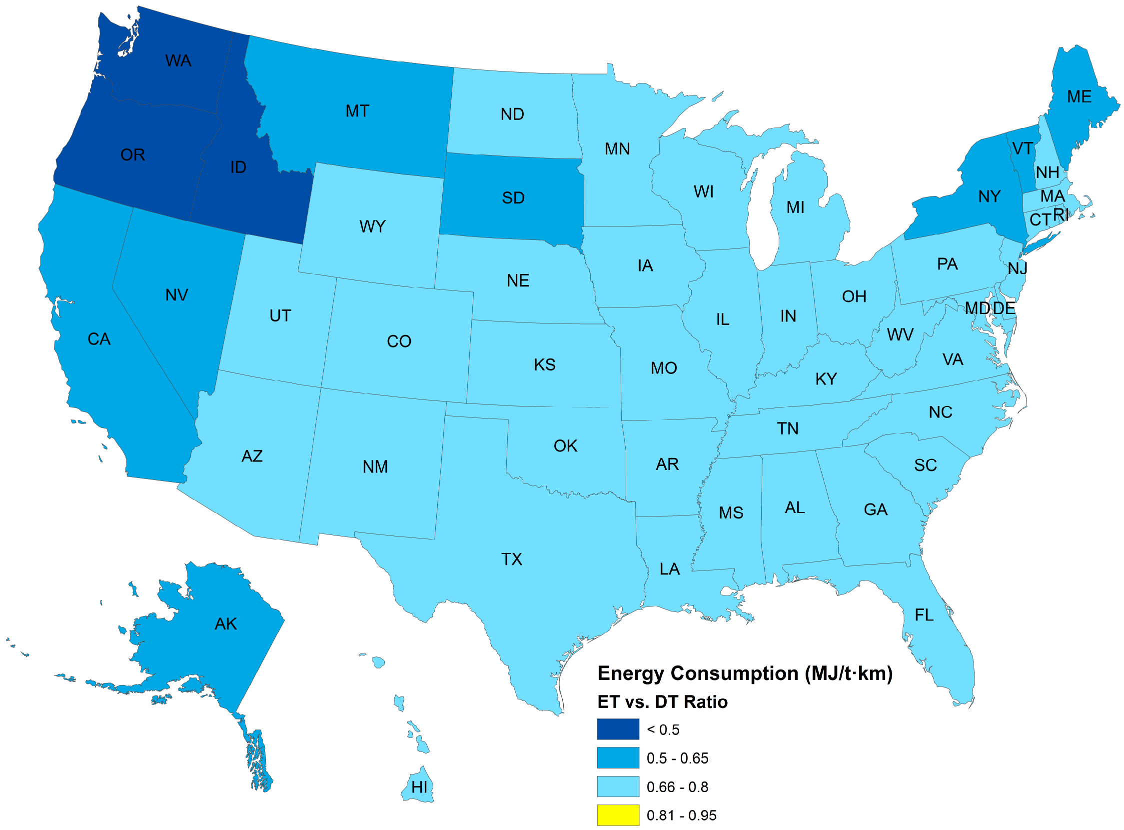
17. Spatio-Temporal Variations of Energy Consumption and GHG Emissions



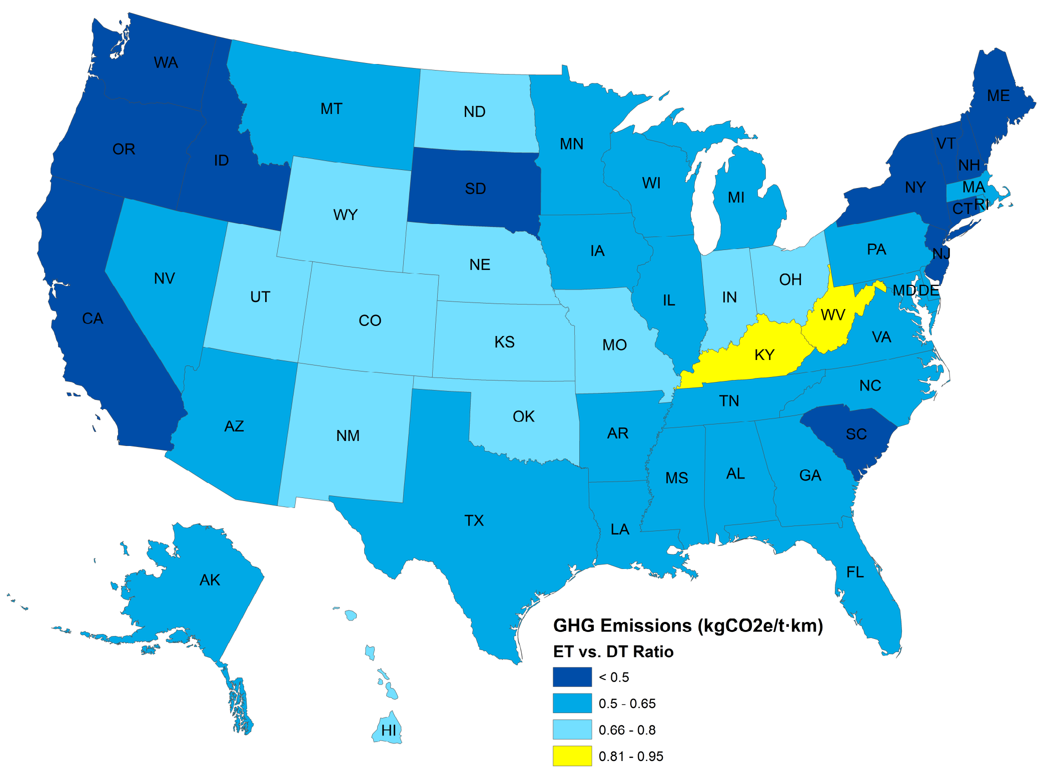
(a) Energy consumption (electric truck vs. diesel truck) – NYCC



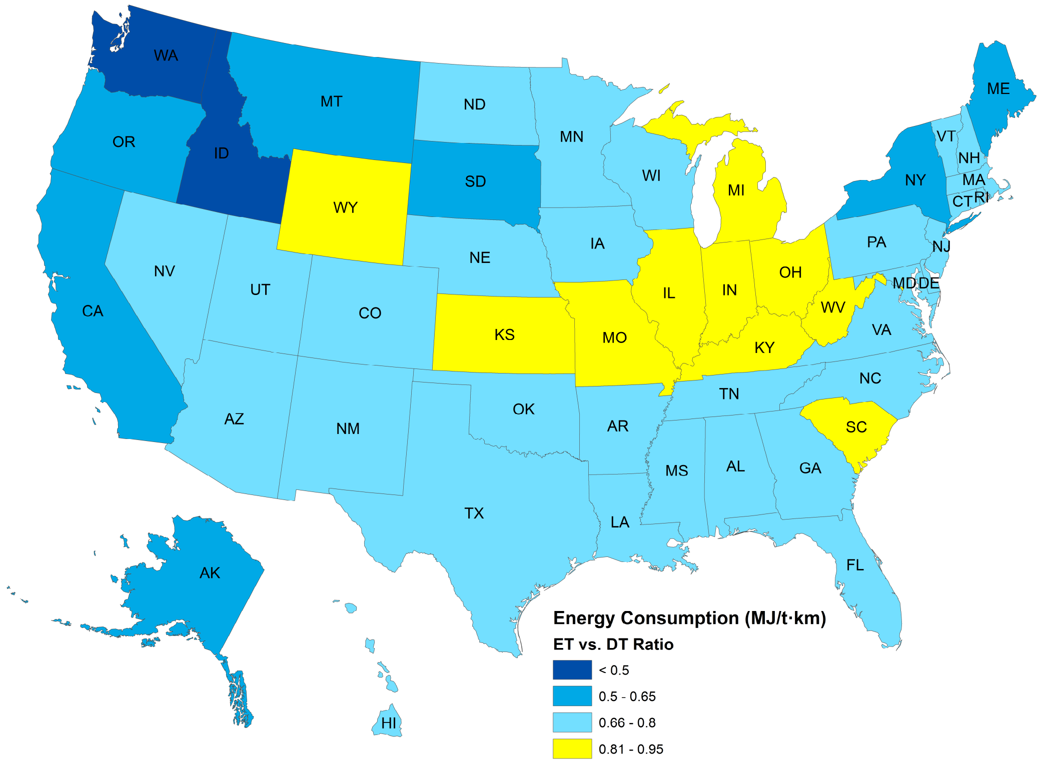
(b) GHG emissions (electric truck vs. diesel truck) – NYCC



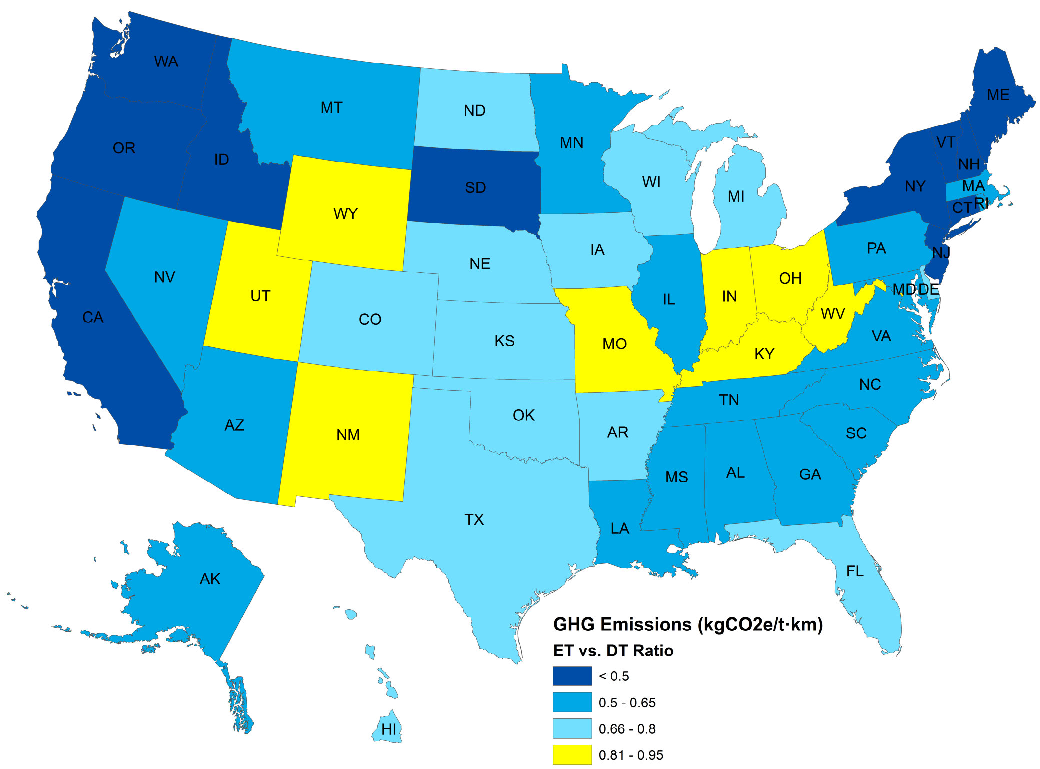
(c) Energy consumption (electric truck vs. diesel truck) – OCTA



(d) GHG emissions (electric truck vs. diesel truck) - OCTA

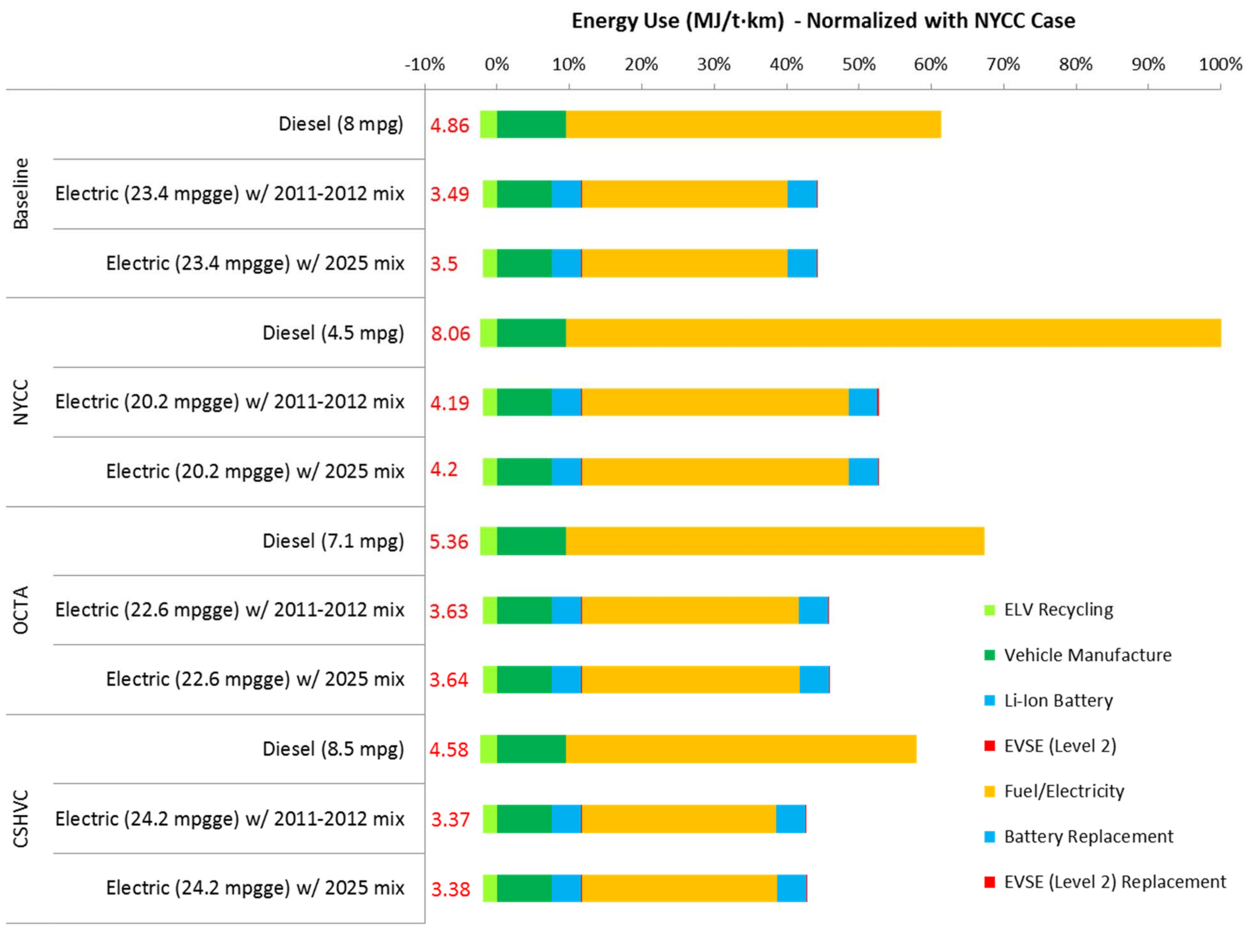


(e) Energy consumption (electric truck vs. diesel truck) – CSHVC

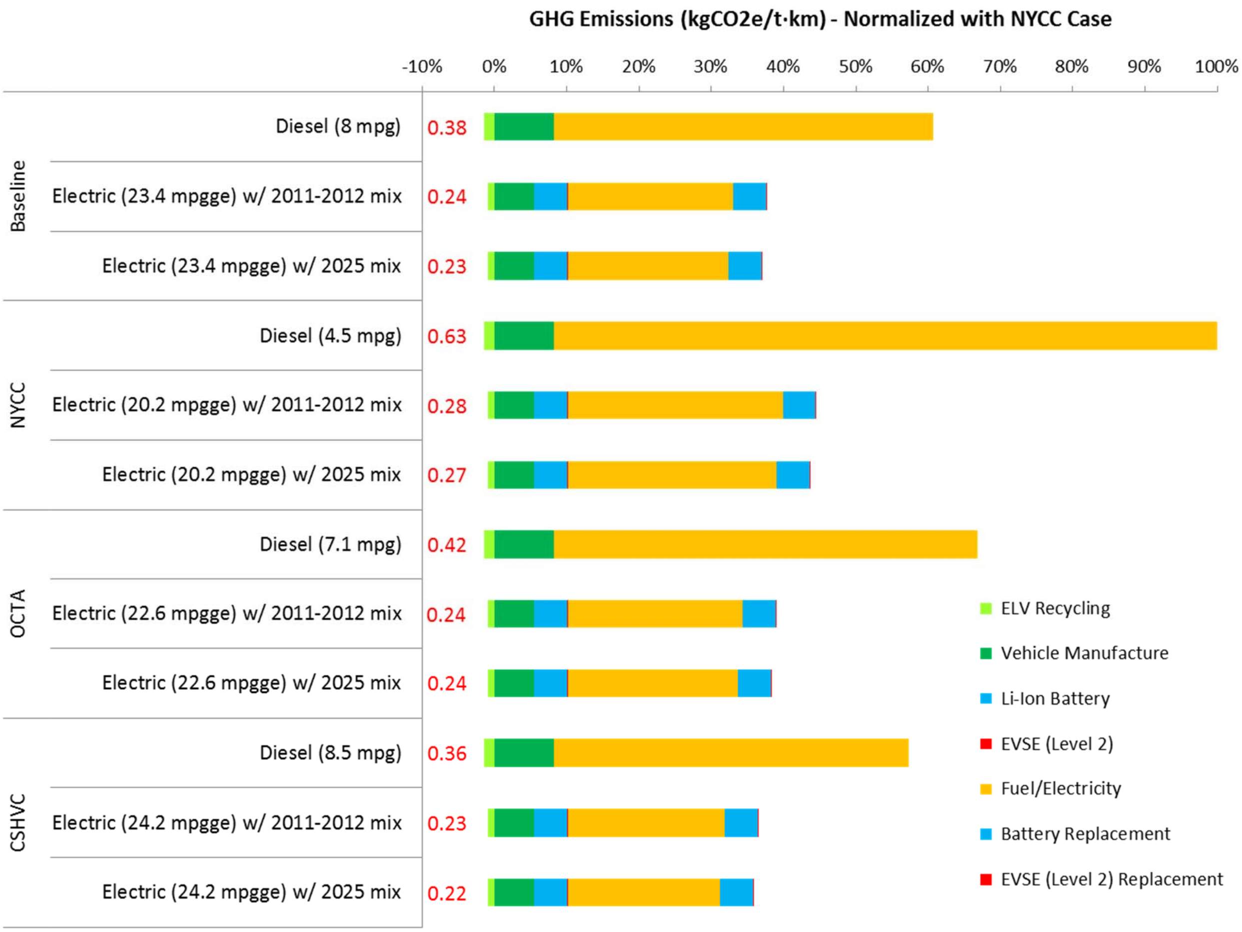


(f) GHG emissions (electric truck vs. diesel truck) - CSHVC

Figure 7S. Spatial variation of energy consumption and GHG emissions.



(a) Energy consumption

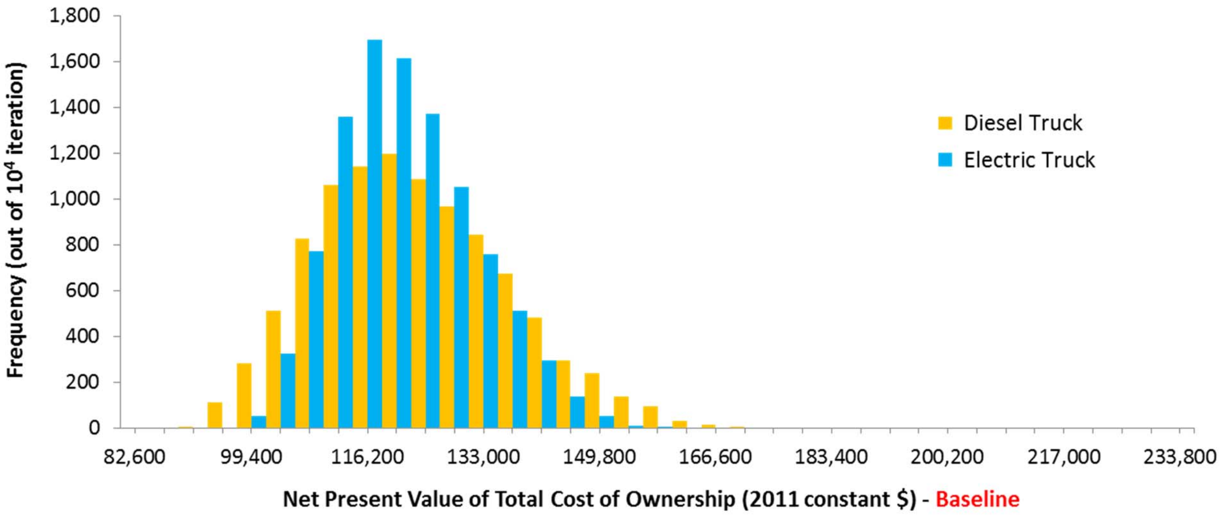


(b) GHG emissions

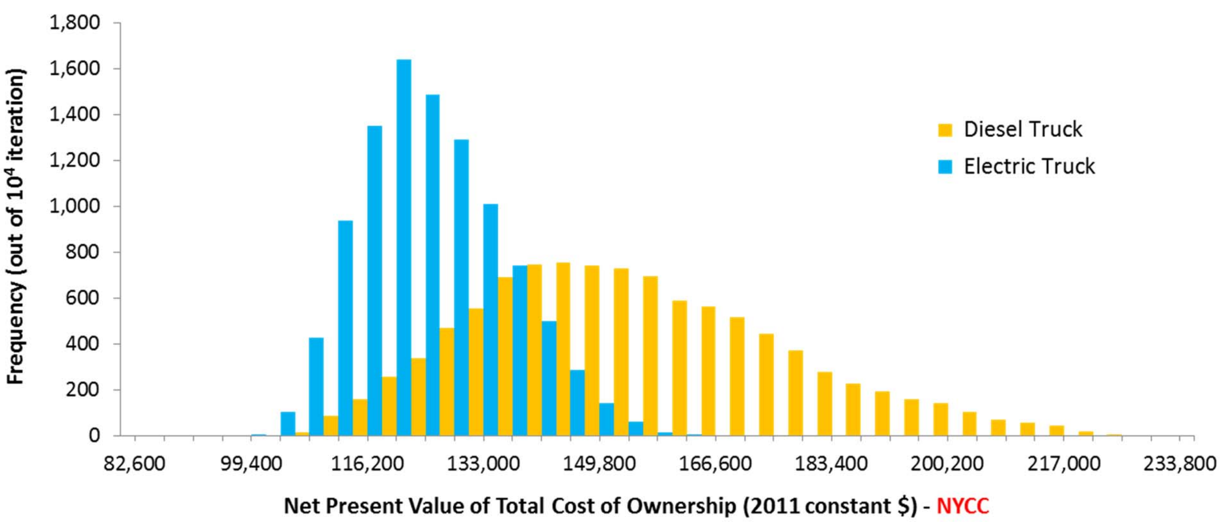
Figure 8S. Temporal variation of energy consumption and GHG emissions with 2011-2012 and 2025 generation mix.

18. Total Cost of Ownership (TCO) Uncertainty Analysis – Additional Charts

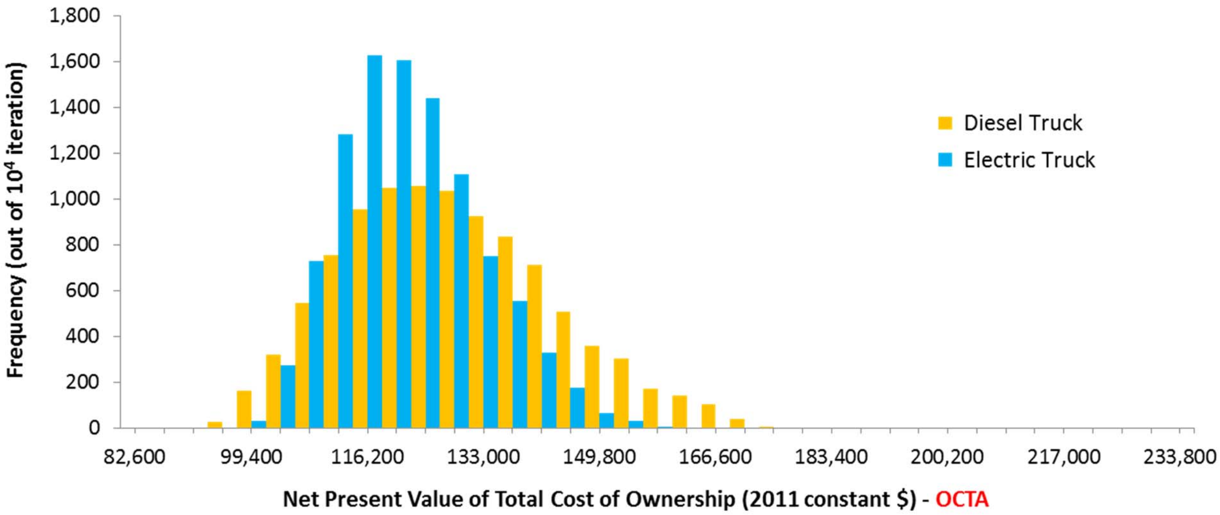
In addition to the NPV distribution chart for the TCO differential for the diesel and electric trucks in the main manuscript (Figure 4), here we present more detailed charts showing the TCO of the diesel and electric trucks separately.



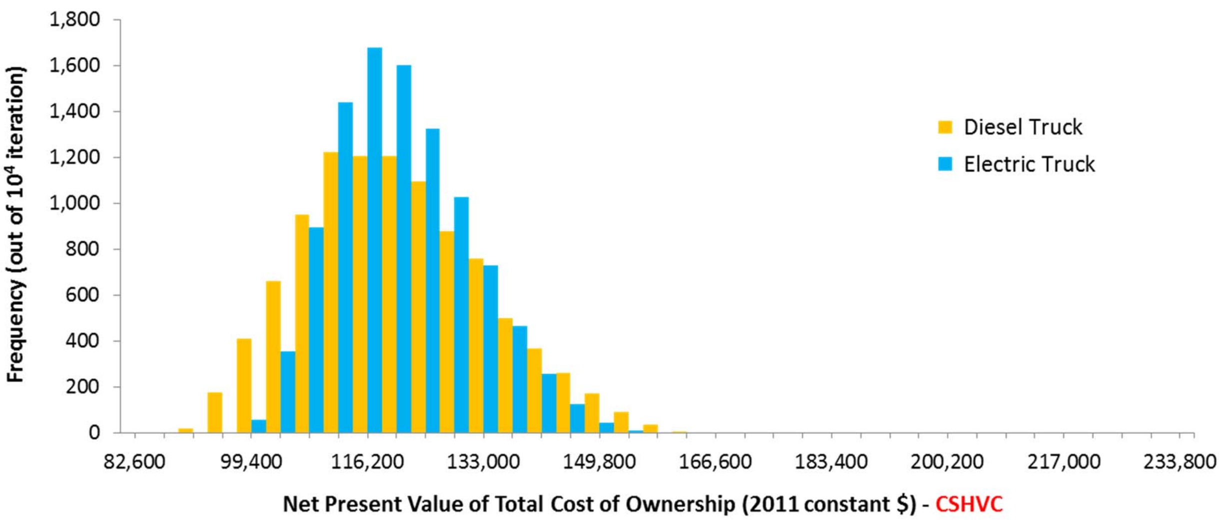
(a) Baseline



(b) NYCC



(c) OCTA



(d) CSHVC

Figure 9S. NPV distribution for different drive cycles based on Monte Carlo simulation.

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